Microstructure Modification for SnBi Low Temperature Solder Alloy

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ABSTRACT
Low-temperature solder alloys lower the processing temperature required for electronic packaging. SnBi alloy system stands out due to its eutectic temperature, which can reach 139°C. However, Bi segregation during aging can compromise the joint's strength. This paper introduces a novel structure for the SnBi-based solder joint at the board level. A layer of SAC alloy or hot air solder leveling (HASL) is applied over the OSP surface finish. An alternative strategy involves the addition of carbon nanofiber (CNF) to adjust the SAC alloy microstructure. The incorporated CNF acts as nucleation sites, transforming the microstructure. Both microstructural modification techniques bolster mechanical strength and shift the fracture mode from brittle to ductile.

Key words: SnBi; low-temperature solder; HASL

INTRODUCTION

Development of low-temperature solder alloys is crucial due to the benefits they offer, including reduced processing temperatures. Such reductions can minimize the warpage of Si dies and decrease the likelihood of device failures from unbonded joints. Furthermore, lower processing temperatures can contribute to the reduction of carbon emissions, a critical step for the industry in achieving its net-zero goals.

The eutectic SnBi alloy boasts a melting temperature of 139°C, which is notably lower than the traditional SnAgCu (SAC) alloy systems with melting temperatures above 210°C. However, the SnBi alloy presents challenges, such as Bi segregation during post-annealing. This segregated Bi is brittle, amplifying the risk of failure when electronic packaging is subjected to stress [1]. An explored solution involved modifying the SnBi composition by alloying it with a trace amount of silver[2, 3]. This adjustment prevented the formation of a continuous brittle Bi-rich layer during the aging process. While the addition of silver enhanced the mechanical properties of the SnBiAg alloy, the fracture surfaces still exhibited brittle characteristics [3].

In our study, we opted for SnBi alloyed with trace amounts of Ag and Cu as a low-temperature bonding material. This blend provides a favorable melting point and superior mechanical properties, mitigating thermal warpage risks and bolstering device reliability over prolonged aging periods [4, 5]. Our research proposes two techniques to adjust the alloy's microstructure. The initial method involves a layered approach: applying a thin layer of SAC305 solder paste or hot air solder leveling (HASL) to the OSP surface finish, followed by screen-printing the SnBi alloy paste on top. Post-reflow, the solder transitions to a hypo-eutectic (Sn-rich) composition. Alternatively, integrating carbon nanofiber (CNF) into the SAC solder has also proven effective to modify the microstructure. The modest CNF inclusion doesn't compromise the solder's thermal attributes and achieves even distribution in solder pastes manufactured at an industrial level. Both strategies effectively refined the microstructure and markedly improving its mechanical strength. As a result, this alloy is posited as an ideal choice for low-temperature assembly applications.

EXPERIMENTAL

An initial layer of SAC solder or HASL Sn was applied to a specified region on a printed circuit board (PCB) and subsequently reflowed at approximately 250°C. This was followed by screen-printing a layer of SnBi solder atop the SAC solder, which underwent a reflow process at 190°C. For controlled aging studies, these samples were encapsulated within vacuum-sealed glass tubes and subjected to elevated temperatures for various durations. A trace quantity of CNF was integrated into the SAC alloy before screen-printing onto the primary layer. For comparison purposes, pure SnBi solder was reflowed and subjected to identical test conditions. Post-processing, samples were polished to elucidate their morphological features. To analyze cross-sectional profiles and ascertain phase compositions within the solder, a Scanning Electron Microscope (SEM, S-300H, Hitachi) coupled with an Electron Dispersive Spectrometer (EDS, model 7582, Oxford Instruments) was employed. Mechanical integrity of the solder joints was quantified using shear test apparatus (DAGE 4000PXY). Additionally, the SEM facilitated the examination of the fracture surfaces, enabling the characterization of the predominant fracture mechanisms.

RESULTS AND DISCUSSION

Reflow results in a two-layer structure in the solder joint, visible in the cross-sectional images (Fig. 1). The top layer consists of SnBi, containing Bi-rich regions. The bottom layer features either SAC solder or HASL Sn. Interdiffusion between Sn from the SAC or HASL layer and Bi from SnBi leads to a shift from eutectic to hypoeutectic SnBi. This shift causes a reduction in Bi-rich areas, especially when compared to reflowed pure SnBi. Within the β-Sn matrix, the eutectic SnBi microstructure becomes evident.

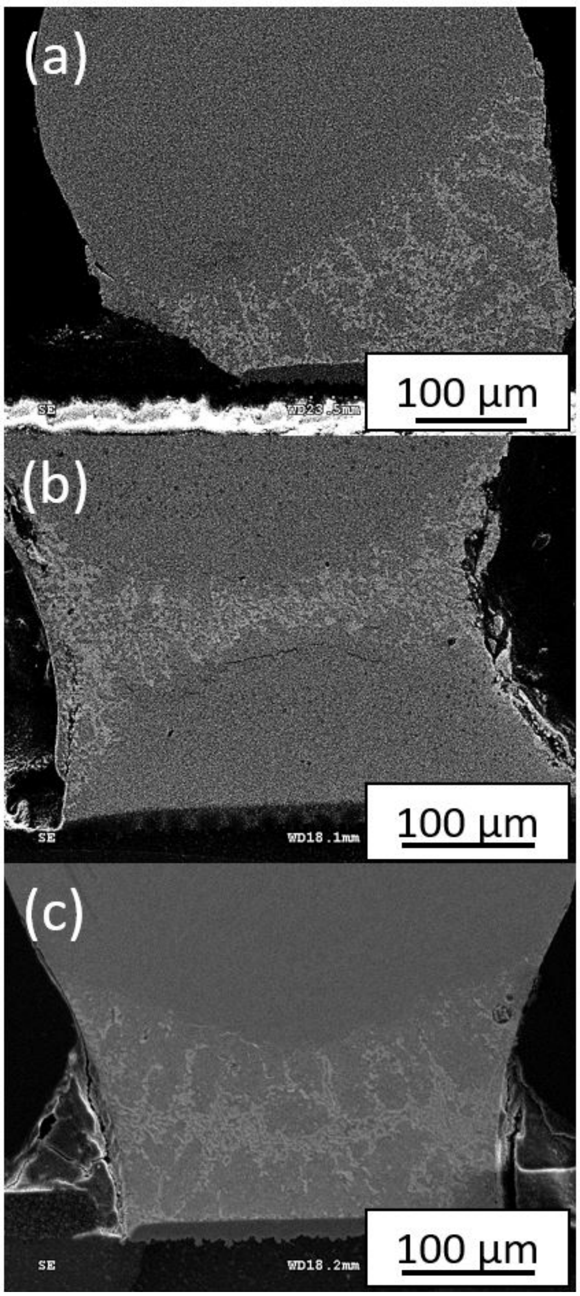

Figure 1. Microstructure of SAC BGA ball on (a) SnBi (b) SAC layer (c) HASL Sn layer

Aging the two-layered solders at 75°C, 100°C, and 125°C results in morphological changes over time. Post-aging, the boundary between the SnBi and either the SAC or HASL Sn layer blurs. Bi-rich regions enlarge, while smaller Bi precipitates appear in the SAC layer. Extended aging deepens the Bi diffusion in the bottom layer, but the area near the substrate remains free from Bi-rich phases.

Shear testing reveals that the strength of the as-reflowed samples remains consistent regardless of the reflowing temperature. Yet, strength notably increases after aging.

Fracture mode is another crucial aspect to consider. Pure SnBi tends to break in a brittle manner, often in Bi-rich areas. Bi segregation weakens the mechanical properties. In contrast, the two-layered solder, especially samples with an SAC foundation, showcases a more ductile fracture pattern (Fig. 2). Here, the SAC layer absorbs stress, and the SnBi layer aids in lowering the reflow temperature. The presence of Bi precipitates in the SAC layer further reinforces the joint after aging.

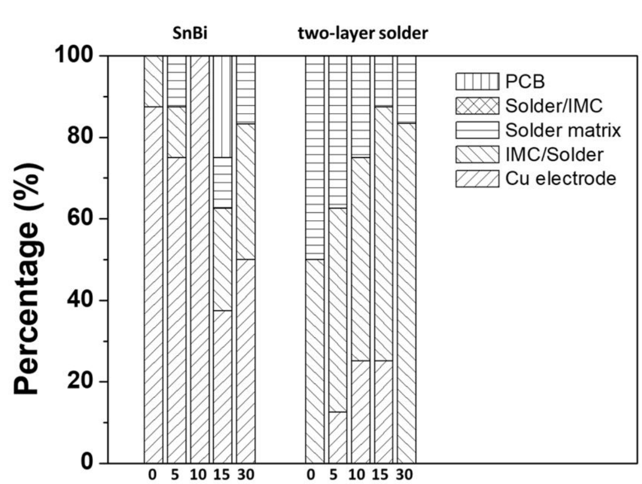

Figure 2. Fracture location in SnBi and two-layer solder for different aging time.

Introducing CNF to the SAC alloy changes its structure. A comparison between SAC alloys with and without CNF is provided in Fig. 3. Without CNF, a dendritic structure is evident. The addition of CNF refines the grain structure, owing to CNF's role as starting points for grain formation during cooling. Furthermore, the refined grains show equiaxed characteristic. This refined SAC solder is expected to offer better joint strength.

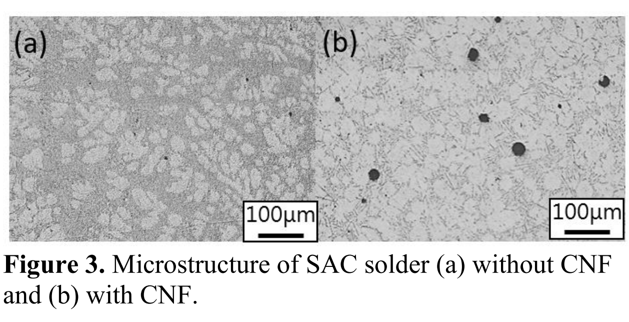

Figure 3. Microstructure of SAC solder (a) without CNF and (b) with CNF.

CONCLUSIONS

The research presents a distinctive two-layer configuration, with SnBi positioned over either SAC or HASL Sn. This design aids in achieving low-temperature assembly, especially beneficial for electronic devices. By integrating CNF into the SAC solder, the microstructure undergoes significant refinement. Detailed morphological evaluations, coupled with mechanical strength assessments, validate a reduction in Bi segregation within these joints. Such a configuration consequently paves the way for an enhancement in the long-term reliability and durability of the soldered joints.

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